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Part X - The Effect of Bedrest on the Circulatory Response to a Valsalva Maneuver

by C. Vallbona, F. B. Vogt, D. Cardus, and W. A. Spencer

Prepared by

TEXAS INSTITUTE FOR REHABILITATION AND RESEARCH

Houston, Texas

for Manned Spacecraft Center

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By C. Vallbona, M.D., F. B. Vogt, M.D., D. Cardus, M.D.,

and W. A. Spencer, M.D.

ABSTRACT

Experimental design of studies of the effect of bedrest carried out at the Texas Institute for Rehabilitation and Research in 1963 included an evaluation of the performance of a controlled Valsalva maneuver before and after bedrest. This report presents the quantitative results of the changes in arterial blood pressure during the performance of a controlled Valsalva maneuver before and after bedrest by a group of thirteen individuals who participated in this study. An analysis of the data indicates that after 14 days of bedrest the Valsalva maneuver may trigger a greater adrenergic reaction to compensate for the decreased venous return in the phase of forced expiration. This adrenergic reaction was evident also in subjects who developed poor tolerance to passive tilt following bedrest. The findings suggest that a mechanism of orthostatic hypotension after bedrest must be explained on basis other than deficit in the autonomic nervous system of these individuals.

FOREWORD

This study is a part of a NASA investigation of the effect of bedrest on various parameters of physiological function. It was sponsored by NASA Manned Spacecraft Center under Contract NAS-9-1461, with Dr. Lawrence F. Dietlein, Chief, Space Medicine Branch serving as Technical Monitor.

This study was conducted in the Immobilization Study Unit of the Texas Institute for Rehabilitation and Research, The Texas Medical Center. The authors are affiliated with Baylor University College of Medicine as follows: Dr. Vallbona, Departments of Rehabilitation, Physiology, and Pediatrics; Dr. Vogt, Department of Rehabilitation; Dr. Cardus, Departments of Rehabilitation and Physiology; and Dr. Spencer, Department of Rehabilitation.

The authors are greatly indebted to Dr. H. E. Hoff for his participation in the planning and realization of this study and for his review of this report. Acknowledgement and appreciation are extended also for the contributions of Dr. T. Watt, Mrs. D. Bellis, Mrs. A. Goldstein, and Mr. T. O. Townsend for their assistance during the experiments; to Mr. R. Lamonte and his assistants of the Bioinstrumentation Section, Space Medicine Branch, MSC-NASA, for their efforts in providing bioinstrumentation support; to Mr. R. Hooker and Miss M. E. Oro for their part in the digitizing of records; to Miss M. Lewis and Mr. F. Rosenbaum for the computer programming of the initial calculations and plotting of the digitized data; to Messrs. W. Blose, T. McBride, and H. Thompson for the statistical analyses; to Dr. M. T. de Caralt for the preparation of the graphs; and to Mrs. S. Gotcher, Mrs. E. Stallworth, and Mrs. L. Shropshire for the editing and preparation of the manuscript.

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SUMMARY

This study was conducted to quantify the magnitude of the changes of the arterial blood pressure during the performance of a controlled Valsalva maneuver before and after bedrest. An analysis of the data indicates that after bedrest the Valsalva maneuver may trigger a greater adrenergic reaction to compensate for the decreased venous return in the phase of forced expiration. This adrenergic reaction was evident also in subjects who developed poor tolerance to passive tilt following bedrest. The findings suggest that the mechanisms of orthostatic hypotension after bedrest must be explained on basis other than deficit in the autonomic nervous system of these individuals.

INTRODUCTION

A forceful expiratory effort against a closed glottis (Valsalva maneuver) produces marked and rapid changes in the heart rate and in the blood pressure. The pattern of these changes has been extensively studied in healthy subjects and in patients affected with different pathological conditions.[1,2,3,4,5,6,7,8,9,10]

Sarnoff and co-workers[4] identified five different phases in the dynamic circulatory response during and after the Valsalva maneuver. The physiological mechanisms of these dynamic changes have been the object of numerous investigations. It has become clear that a constellation of mechanical and reflex factors account for the typical responses in blood pressure and heart rate.

There is a high degree of activity of the autonomic nervous system at different phases of the Valsalva maneuver because the increased intrathoracic and intraabdominal pressures produce hemodynamic changes which trigger compensatory response of the sympathetic and parasympathetic systems.[11,12,13,14] The pattern of the circulatory responses during the maneuver depends a great deal on the conditions under which the test is carried out.[15] When the conditions are controlled according to specific standards (Flack test),[16] much information can be gained on the behavior of the autonomic nervous system of the individual tested.

If the assumption is correct that prolonged bedrest may affect the cardiovascular condition of the individual, it seemed appropriate to evaluate whether or not prolonged bedrest alters the normal pattern of changes of hemodynamics during the Valsalva maneuver. Furthermore, it seemed appropriate to evaluate the possible influence of a program of isometric exercises carried out in the supine position during bedrest.

This report presents and discusses the hemodynamic changes observed during controlled Valsalva maneuvers performed by healthy subjects before and after bedrest.

METHOD

A. Subjects

Thirteen subjects participated in two studies. The first study (six subjects took part) consisted of two separate periods of 3 days of bedrest. The subjects remained horizontal in bed in the first period. They did isometric exercises in the recumbent position during the second period.

The second study was aimed at evaluating the effect of bedrest for two 14-day periods. Six subjects participated in the first 14-day period. Five of the same subjects and a new person participated in the second 14-day period during which the subjects performed isometric exercises in the recumbent position.

Details of the experimental design for the two periods of this study have been given in a separate report.[17]

B. Procedure

The subjects received adequate instructions on how to perform the controlled Valsalva maneuver (Flack test) before the actual testing. The subject had to blow hard against a mouthpiece that contained a spring-loaded piston. This offered a resistance to air flow through the mouthpiece. The resistance had been previously calibrated, and it was possible to determine that a given position of the piston corresponded to an airway pressure of 40 millimeters of mercury.*

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*The device had been developed at the NASA Manned Spacecraft Center, Houston, Texas.

In the first study, each subject performed two Valsalva maneuvers before and after bedrest. One was done immediately after the subject had been tilted to 70° and the other at the end of the third minute after the subject returned to the supine position. Recordings of the heart rate and arterial blood pressure showed that the subjects had achieved the steady state when they were tested at 0°, but the subjects were still under the effect of a slight transient response to passive tilt when they did the Valsalva maneuver in the vertical posture. At the time of setting up the experimental design, it was felt that the transient response to tilt would not alter the cardiovascular reaction to a Valsalva maneuver. The duration of the forced expiration varied from subject to subject and from day to day. It usually lasted from 15 to 25 seconds.

In the second study, each subject performed one Valsalva maneuver in the supine position before and after bedrest. The maneuver was done at the end of a passive tilt test after return of the recorded hemodynamic values to a steady state.[17] The duration of the Valsalva maneuver was 15 seconds in all the subjects on all the days of testing.

C. Recordings

The subjects were monitored continuously during the process of cardiovascular evaluation which included a passive tilt test in addition to the Valsalva maneuver. The monitored variables were the electrocardiogram, phonocardiogram, carotid pulse tracing. radial pulse tracing, intraarterial blood pressure, cardiotachogram, and airway pressure.

These variables were displayed on a Sanborn eight-channel oscilloscope and were simultaneously recorded on analog magnetic tape. The analog data collected on tape were played back on a direct writing instrument (Offner Dynogram) at a paper speed of 0.5 centimeters per second (figure 1).

The details of the tilt procedure are available in a previous report.[17]

The instrumentation used for this study had been assembled by the Bioinstrumentation Section, Crew Systems Division, NASA Manned Spacecraft Center, Houston, Texas.[18]

D. Measurements

The records of the intraarterial blood pressure and of the cardiotachogram were digitized by means of a Benson Lehner OSCAR Model E analog-to-digital converter. Digital readings of the systolic and diastolic blood pressure and of the cardiotachogram were obtained as follows: (a) in at least eight points during the steady state prior to the Valsalva maneuver, (b) at the point of maximum initial rise of the blood pressure, (c) at the point of lowest blood pressure during the period of forced expiration, (d) at the peak of the compensatory effort, (e) at the moment of release of the expiratory effort, (f) at the peak "overshoot", and (g) in ten additional points after the peak "overshoot" until a steady state had been achieved.

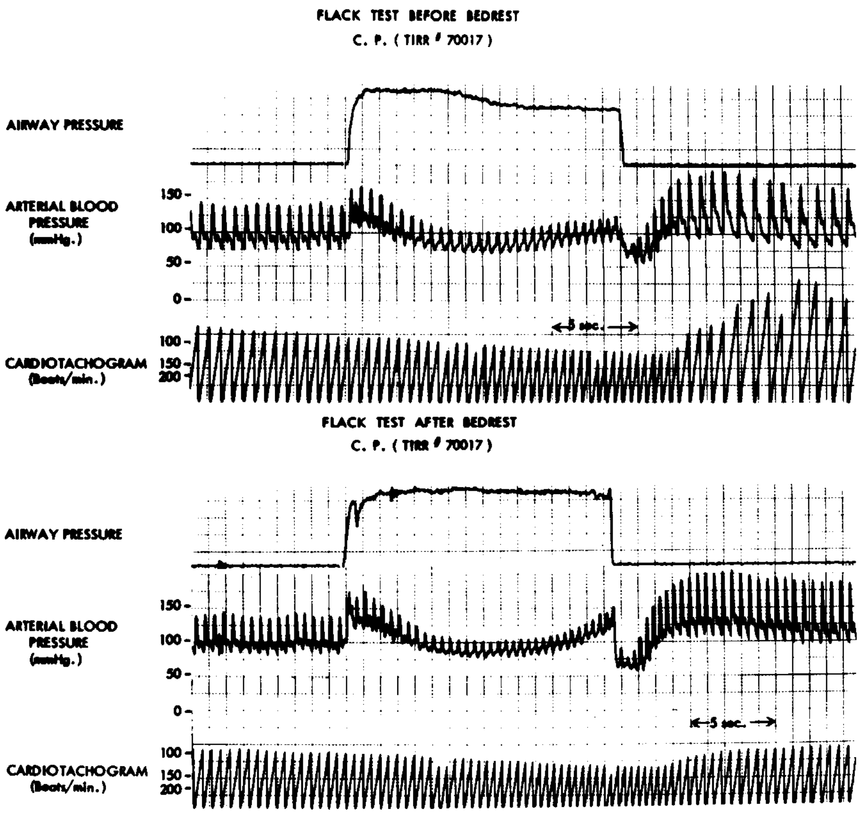

FIGURE 1

The record at the bottom, which was obtained after 14 days of bedrest without exercise shows a higher compensatory rise of the blood pressure during Valsalva and a higher and more sustained "overshoot". The instantaneous heart rate is higher and the deceleration at the phase of "overshoot" is not as marked as in the test before bedrest.

Recordings of the airway pressure (obtained by connecting the mouthpiece to a Statham pressure transducer) indicated that the subjects maintained a constant expiratory effort throughout the procedure. Also, the recordings illustrated a clear distinction of the onset and termination of the expiratory effort.

In the position of tilt the records of the intraarterial blood pressure had to be corrected for an error introduced by the weight of the column of blood between the gauge of Statham transducer and the point of the needle insertion in the brachial artery. This correction was not applicable to the recordings made in the supine position.

E. Computation of Data

The digital readings of the systolic and diastolic blood pressure, of the RR interval of the electrocardiogram (as presented in analog form by the cardiotachogram), and of the airway pressure were the input data for a computer program that calculated the mean blood pressure, differential blood pressure, heart rate, stroke volume, cardiac output, and peripheral resistance at each of the points of digitization. A computer program developed previously for analysis of the time constant of the recovery of the heart rate after exercise[19] was adapted for the analysis of the rates of change of blood pressure after the "overshoot".

RESULTS

The patterns of the changes of blood pressure and heart rate during the performance of the Valsalva maneuver were similar in all these subjects and in agreement with data presented by other investigators.[5,6,9]

The average measurements of the mean blood pressure for the group of six subjects who participated in the first study (3 days of bedrest) showed a large coefficient of variation at each day of testing. Also, differences in the duration of the test precluded valid comparisons.

Figure 2 depicts the changes of the mean blood pressure throughout the Valsalva maneuver before and after the first period (bedrest alone). The dotted line of mean blood pressure after bedrest shows higher values at the steady state before the maneuver (a) at the peak of initial rise (b), at the "overshoot" (f), and at the final steady state (g). The time constant of the phase of recovery was longer also after bedrest.

Figure 3 shows the changes of mean blood pressure throughout the Valsalva maneuver before and after the second period (bedrest with isometric exercise). The dotted line shows essentially the same values of mean blood pressure in the two tests. The differences at "overshoot" (f) was not significant. Likewise there was no significant difference in the values of the time constant of the recovery.

		Value Before Maneuver	Initial Rise	Lowest Value	Highest Compensatory Value	Lowest Value at Release	Overshoot	Value at $T_{0.63}$	Value of $T_{0.63}$*	Final Value
Before Bedrest (7-22-63)	Mean	93	131	102	132	90	113	100	7.8	93
	St.Dev.	7	10	5	22	13	17	9	2.8	9
After 14 Days of Bedrest (8-5-63)	Mean	102	145	96	130	88	132	112	13.2	101
	St.Dev.	7	14	4	16	18	15	6	3.0	6
p		< 0.05	< 0.05	-	-	-	< 0.001	< 0.02	< 0.05	< 0.10
Before Bedrest with Exercise (8-19-63)	Mean	96	133	91	131	92	124	106	7.6	95
	St.Dev.	5	6	8	20	14	9	4	2.9	6
After 14 Days of Bedrest with Exercise (9-2-63)	Mean	96	135	88	132	92	120	105	9.6	96
	St.Dev.	3	7	6	32	23	8	5	4.0	5
p		-	-	-	-	-	-	-		-

All values of mean blood pressure are given in mmHg.

*This value is given in seconds and represents the interval from the peak "overshoot" to the point of recovery when the amplitude of the mean pressure dropped by 63% to a final steady state value.

TABLE I

AVERAGES AND STANDARD DEVIATIONS OF VALUES OF MEAN BLOOD PRESSURE DURING THE VALSALVA MANEUVER

THE EFFECT OF BEDREST ON THE CIRCULATORY RESPONSE
TO A VALSALVA MANEUVER
(STUDY II PERIOD 1)

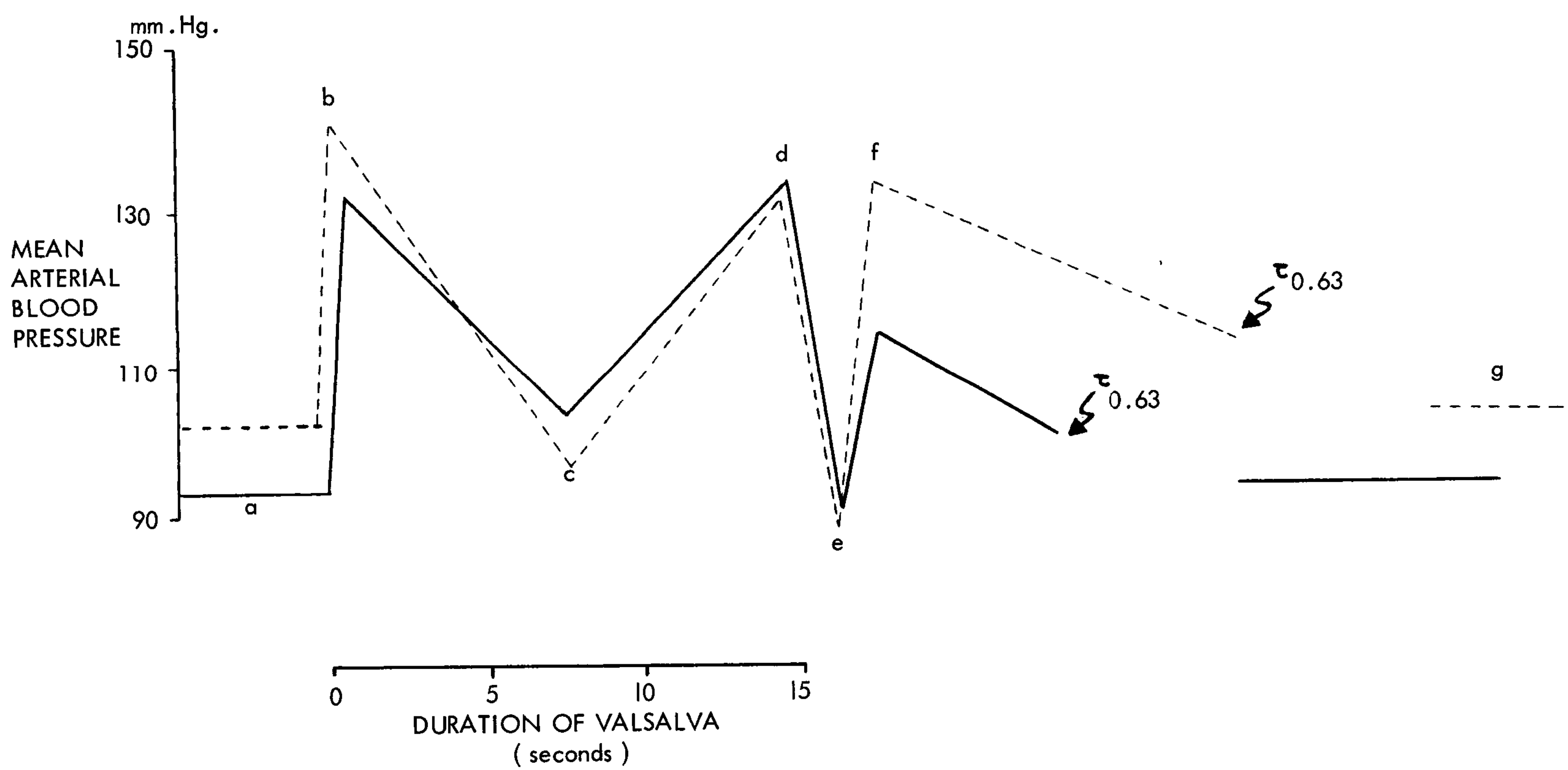

FIGURE 2

The solid line shows the changes in mean blood pressure of a group of six subjects before 14 days of bedrest without exercise. The dotted line shows the changes in the same group of six subjects after bedrest without exercise.

THE EFFECT OF BEDREST ON THE CIRCULATORY RESPONSE
TO A VALSALVA MANEUVER
(STUDY II PERIOD 2)

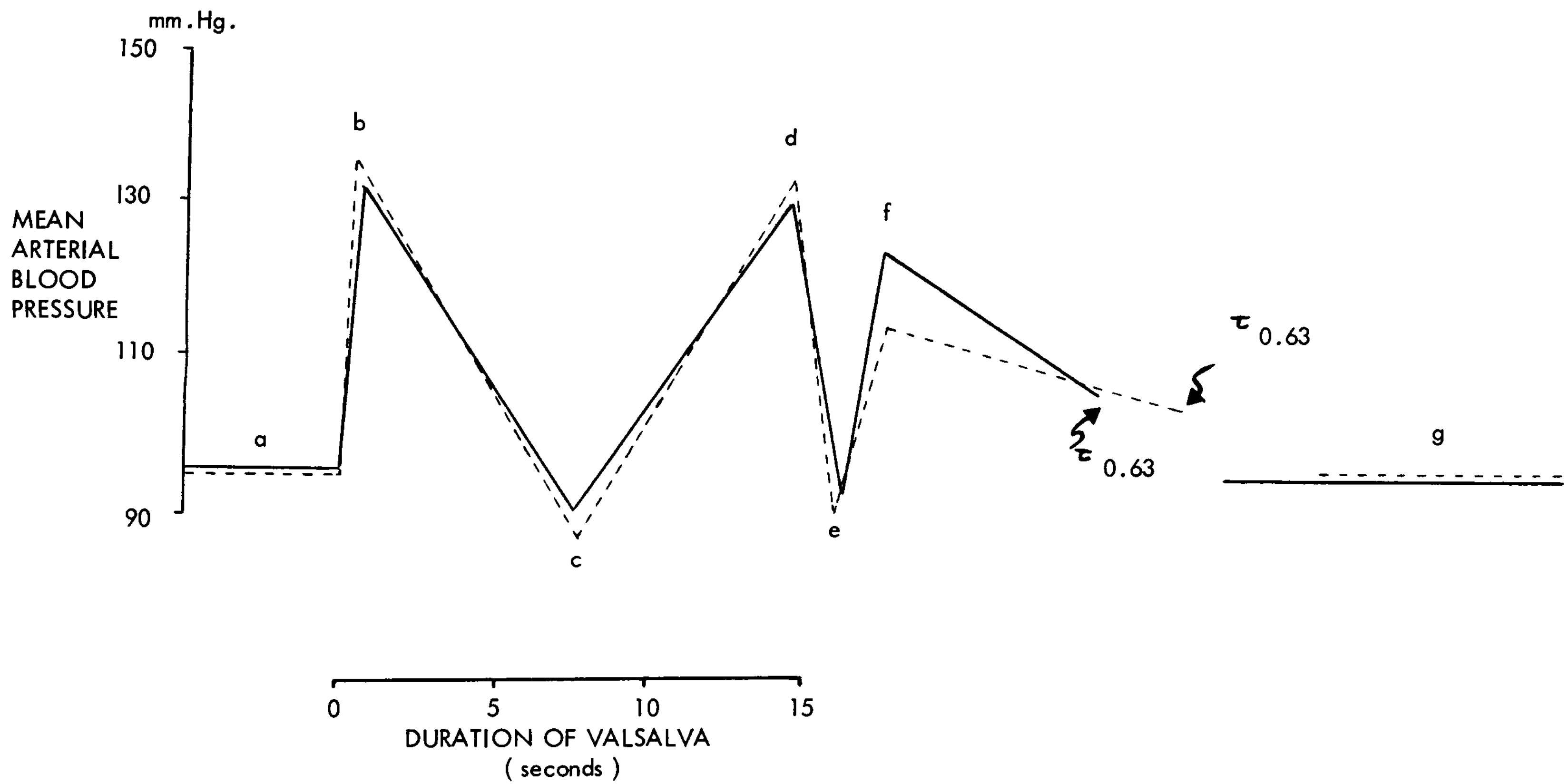

FIGURE 3

The solid line shows the changes in mean blood pressure of a group of six subjects before 14 days of bedrest with exercise. The dotted line shows the changes in the same group of six subjects after bedrest with exercise.

Table I shows the results of the statistical analysis of the values depicted in Figures 2 and 3.

DISCUSSION

The pattern of changes in mean blood pressure during the performance of a Valsalva maneuver after 14 days of bedrest suggests an increased sympathetic response to the hemodynamic effects of a forced expiration. The increased sympathetic tone was manifested by the higher "overshoot" at the release of the intrathoracic pressure and by a prolonged time constant of this "overshoot". This observation is in agreement with the impression advanced in previous reports[17,20] that bedrest is associated with an adrenergic reaction.

Since the Valsalva tests were done 3 minutes after passive tilt, one must consider the possible effects of this passive tilt on the circulating blood volume and on the amount of blood contained in the pulmonary circulation. Sjöstrand[21] has demonstrated that upon return to the horizontal position after passive tilt (feet down) there is considerable displacement of the circulating blood volume from the lower extremities to the lungs. This displacement may have occurred very rapidly in the tilts of the healthy subjects before bedrest, but it is likely that it occurred much more slowly after the tilts at the end of the first period of bedrest. If this assumption is correct, it would imply that during the Valsalva test there is a greater diminution of the venous return to the right heart and this could have triggered the exaggerated response that accounted for the "overshoot" at the moment of release of the pressure. Unavailability of blood volume measurements precludes confirmation of the hypothesis.

The response to the Valsalva maneuver described here was not evident in all the subjects. One of the individuals who developed impending syncope during the tilt test after bedrest had a decreased compensatory rise in the phase of increased expiratory effort; but in this individual, the "overshoot" was manifest and sustained. This is in contrast with the observations of Marshall and co-workers[22] who reported a small compensatory rise and a markedly decreased "overshoot" in patients with idiopathic orthostatic hypotension. It is likely that the deficit of the autonomic nervous system, which is characteristic of individuals with idiopathic orthostatic hypotension[6,14,22] does not exist in subjects after bedrest. The poor tolerance to passive tilt after bedrest, therefore, should not be explained on basis of a decreased responsiveness of the sympathetic system.

Although the Valsalva maneuver following 14 days of bedrest with exercise did not produce the exaggerated sympathetic response observed after bedrest alone, this should not be taken as evidence against the reported increased adrenergic reaction of the subjects who participated in the program of isometric exercise in the supine position.[17,20] It is conceivable that during the maximal expiratory effort carried out at the end of bedrest with exercise, the hemodynamic changes were not as brisk as when the test was done following bedrest alone. Because of this, a compensatory rise of the blood pressure was not necessary. A protective effect of the program of isometric exercises during bedrest is suggested by these results as well as by the results of passive tilt tests.[17]

The technique used in this study to analyze quantitatively the results of a Valsalva maneuver showed that there is a great deal of individual variability in the circulatory response to a forced expiration with a closed glottis. Emotional factors may account for some of the changes observed such as an increase in the cardiac frequency and in the blood pressure just before starting the Valsalva maneuver (figure 4). These changes were observed in two subjects before each Valsalva maneuver regardless of the day. It was observed also in three other subjects but not in all the tests they performed. This observation is comparable to changes in circulatory dynamics in anticipation to physical exercise[23] and adds complexity to the understanding of the exact mechanisms that intervene in the control responses of a Valsalva maneuver. It is unlikely, though, that emotional factors could account for the higher "overshoot" in the tests after bedrest.

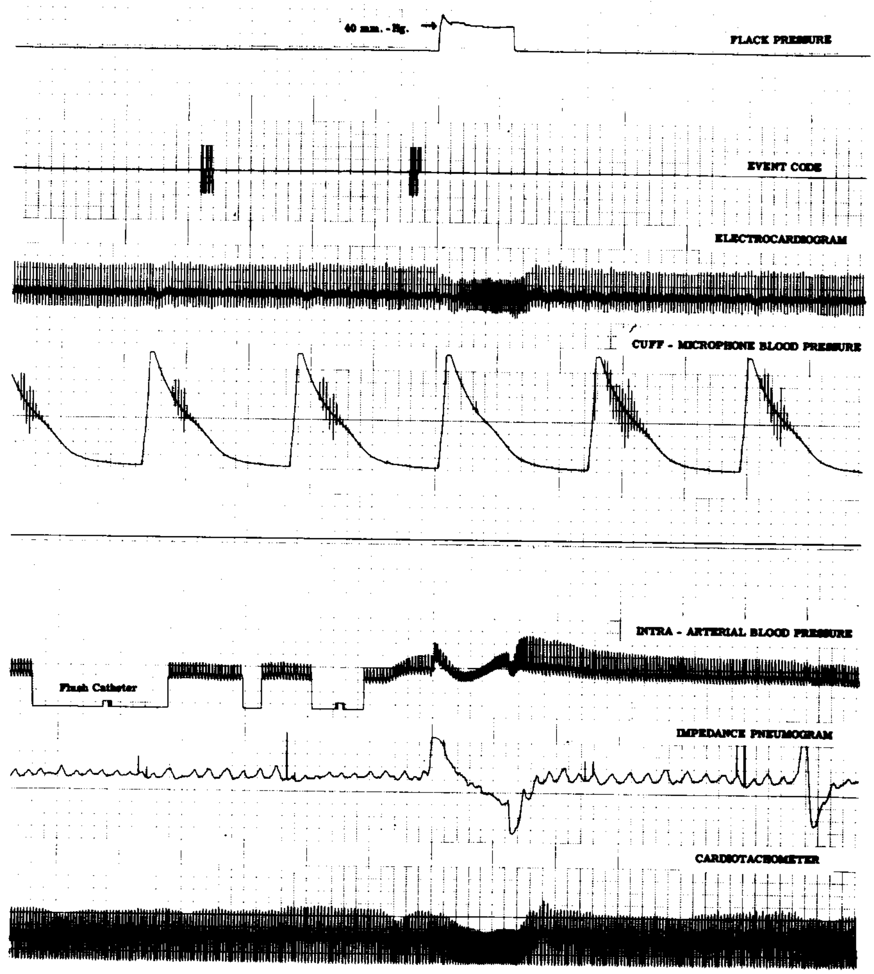

FIGURE 4

Analog record of response to Valsalva maneuver of healthy subject TIRR #70012. The record shows an increase in arterial blood pressure in anticipation of the test.

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